Purdue University
Purdue e-Pubs

International Compressor Engineering Conference

School of Mechanical Engineering

1990

Development of a Scroll-Type Oil-Free Vacuum Pump

T. Kushiro
Shin Meiwa Industry Co.

K. Miyazaki
Shin Meiwa Industry Co.

H. Kataoka
Shin Meiwa Industry Co.

S. Nii
Shin Meiwa Industry Co.

S. Machida
Hitachi

Development of a Scroll-Type Oil-Free vacuum Pump

Toshio Kushiro, Kazuaki Miyazaki,
Hiroyuki Kataoka, Satoshi Nii, Shigeru Machida*
Shin Meiwa Industry Co., Ltd. JAPAN
*Hitachi, Ltd. JAPAN

1. ABSTRACT

If oil is to be eliminated from scroll-type pumps, then alternative means must ... ...nd to provide the functions of oil – lubricating, cooling, and sealing – in its absence. This paper describes some of the technical problems that had to be overcome in order to provide these functions without oil. Among these problems, particular attention is focused on thermal deformation of the orbiting scroll and the effect this has on centrifugal force; after describing the phenomenon itself, the causes, proposed measures for resolving the problems, and the results of applying the proposed solution are reported.

2. INTRODUCTION

For applications such as semiconductor fabrication and optical coating systems, rotary-vane pumps have commonly been employed to cover the rough-vacuum range. However, there are a number of drawbacks associated with this type of pump: they use oil which can backstream to contaminate the process and maintenance costs are quite high due to the deterioration of oil by the process gas. Considerations such as these created a demand for oil-free pumps starting about 10 years ago.

In response to this demand, oil-free pumps began to appear on the market about 5 years ago. Different types of oil-free pumps have been developed including multistage Root's, screw, claw, and combination Root's-claw types. All of these types, however, suffer in comparison with conventional oil-sealed rotary pumps, in that they are overly large, heavy, noisy, and expensive to operate.

On the other hand, scroll configurations with oil-sealed compressors are available that offer a number of significant advantages: gas compression is continuous so fluctuations in torque and pressure are minimal, they are easy to muffle, and because a single stage can be separated by seals into 3 to 4 chambers, low pressures can be attained.

With the object of exploiting these advantages, the authors set themselves the task of developing an oil-free scroll-type vacuum pump. Numerous technological hurdles were encountered as a consequence of eliminating oil. Here we describe some of the chief difficulties and how we resolved those problems to successfully develop a pump that is extremely quiet to operate and compact in size.

3. CONFIGURATION AND SPECIFICATIONS

A cross-sectional view of the pump is shown in Fig. 1, and the main specifications are listed in Table 1. The scroll configuration is generally known and is thus omitted from the figure.

The pump consists of a motor to drive the orbiting scroll, a vacuum chamber housing both the orbiting and fixed scroll members, and seals to keep the motor and the vacuum chamber isolated.

The orbiting scroll is connected to the end of the crankshaft by a roller bearing, and the crankshaft is driven by a motor. Free rotation of the orbital scroll is restrained by

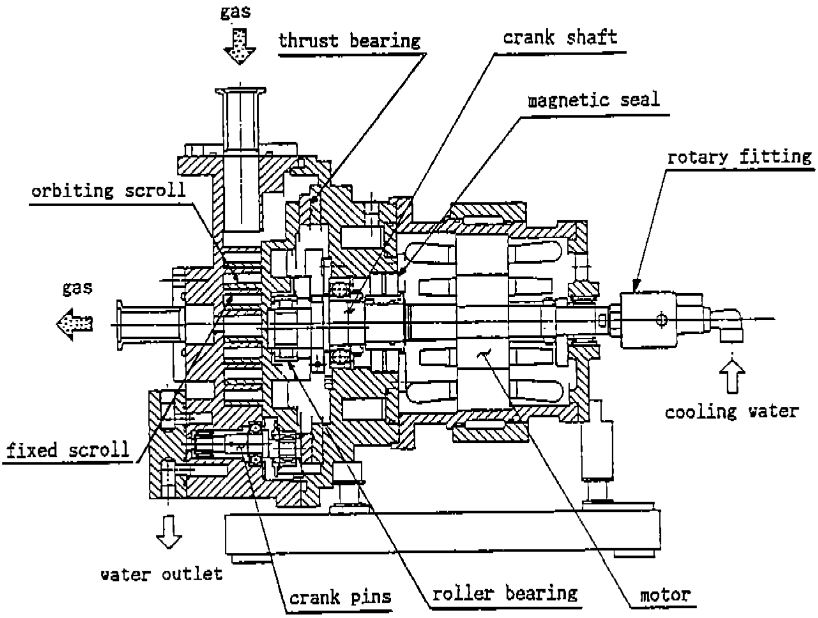


Fig. 1 Cross-sectional view of the pump

crank pins mounted at three points along a ring. The orbiting scroll follows a rotational motion with respect to the fixed scroll which is stationary. This enable gas to be fed in, compressed, and then discharged.

Table 1 Specifications

exhaust rate	0.01m³/s (600ℓ/min)
ultimate pressure	0.5Pa (5×10^{-3}Torr)
motor power	1.5kW
noise level	55dB(A)
dimensions	392W×685L×521H
weight	735N (75kgf)

The vacuum chamber and the motor on the atmospheric side are isolated by magnetic seals.

The motor, magnetic seals, roller bearing, and bearings for the crank pins are water cooled by means of cooling circuits. In the compression chamber, however, the temperature is maintained as high as practical (about 100℃) to prevent the process gas from depositing.

4. PROBLEMS THAT STEM FROM ELIMINATING OIL: PHENOMENA AND CAUSES

There are two key problems that must be solved if a scroll-type oil-free vacuum pump is to be realized:

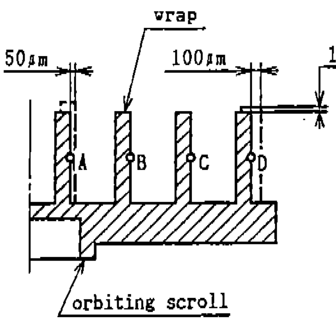
(1) How to handle the thermal deformation of the orbiting scroll member that inevitably occurs because oil is unavailable to provide cooling and because the orbiting member is in vacuum condition and thus there's no means to vent the heat that builds up. Also, since the thermal deformation can interfere with the free rotation of the orbiting scroll and this has an adverse-structural impact, some measure must be [illegible] to counter this effect.

(2) How to alleviate the adverse effects of the centrifugal force that is inevitably generated by the crankshaft drive and which is a major destabilizing factor on the motion of the orbiting scroll.

4.1 Thermal deformation of the orbiting scroll

(1) Contact between the two wraps

Figure 2 shows the temperature distribution and the amount of expansion in the radial and axial directions that occur when a temperature of about 85℃ is applied to the central part of the



location	temperature(℃)
A	82
B	75
C	65
D	50

Fig. 2 Temperature distribution of the orbiting scroll

orbiting scroll. In the case of the fixed scroll, since it is made of aluminum alloy and is exposed to cooling water, the thermal expansion is less: on the order of about 30μm.

Given these circumstances, and particularly if no measure is adopted to cope with the thermal expansion, the wraps of the orbiting and fixed scrolls will come into contact. And since oil is no longer available to provide lubrication between the wraps, the surface coating (Poly Tetra Fluoro Ethylene) is stripped away, and increasing friction could cause a seizure. Collision of the wraps also causes the orbiting scroll to recoil, and since no oil is present to provide damping, a knocking noise and vibration are produced.

(2) Constraint by the crank pins

The relative positions of crankshaft, orbiting scroll, and crank pins are shown in Fig. 3. The center distances of the crankshaft and crank pins, and the center distances of their eccentricity (offset ε), must always be equal to l even when the pump is at rest or being operated in reverse.

As can be seen in Fig. 3, however, the orbiting scroll is subject to thermal expansion in the radial direction at startup

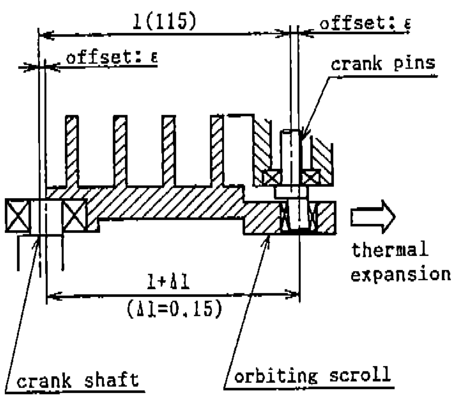


Fig. 3 Orbiting scroll under constraint of crank pins

(refer to Fig. 2), with the effect that l expands to $l + \Delta l$. With this particular type of pump, when l = 115mm, $\Delta l \fallingdotseq$ 0.15mm. Another factor contributing to the vibration is the disparity in machined dimensions of the distance separating the axis. Also, when the load caused by obstructed rotation is not smoothly distributed among the three crank pins, this is also thought to exacerbate, the vibration. All in all, our initial prototype generated a vibrational acceleration of about 4G.

(3) Target performance shortfall

The operating principle of a scroll pump is familiar: gas is taken in between the wraps of the orbiting and fixed scroll members, where it is gradually compressed as it is moved toward the exhaust in the center by the action of the pump. If the gap between the two wraps is too wide, since oil is no longer available to act as a seal in an oil-free pump, the process gas can leak out thus making it virtually impossible to attain the specified pressure (about 0.5Pa).

4.2 Effect of centrifugal force on the orbiting scroll

(1) Unstable motion

The structure that supports the load acting on the orbiting scroll in both radial and axial directions is shown in Fig. 4. Here, point G is the orbiting scroll's center of gravity, point B is the center of the roller bearing that supports the load in the radial direction, and L is the distance between the two points.

In oil-sealed type scroll compressors that are already in practical use, a portion of the outlet pressure leads the backplate of the orbiting scroll so the orbiting scroll is forcefully pushed into engagement with the fixed scroll.

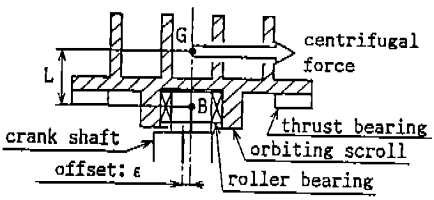


Fig. 4 Centrifugal force acting on the orbiting scroll

In this case, since oil is present between the two scrolls, the amount of friction is minimal and smooth relative motion is achieved. And this isn't all: the compression performance is improved because the axial gap between the wraps is reduced to zero, and improved stability results because the oscillating motion of the orbiting scroll is suppressed.

In an oil-free scroll vacuum pump, as was described above in Section 4.1, the two scrolls have to be maintained far enough apart so there is no danger of them colliding. As shown in Fig. 4, however, if the crankshaft driving the pump contains an offset amount of ε, then a centrifugal force proportional to ε acts on the orbiting scroll (shown by the arrow in the figure).

Since the orbiting scroll is supported at B, the moment of force, multiplied the centrifugal force by L, acts on the orbiting scroll: this causes oscillating vibration centered around point B, and a rattling sound of the thrust bearing.

5. COUNTERMEASURES AND IMPLEMENTATION RESULTS

5.1 Thermal deformation of the orbiting scroll

(1) Contact between the two wraps

A method that effectively prevents the two wraps from coming into contact is shown in Fig. 5. As illustrated in the figure, the outer portion of the wrap spiral (the outer wall) is made 80μm, while the inside is made only 50μm, somewhat smaller than a theoretical involute curve. Implementing this correction, starting from zero in the center of the wrap spiral (the inner wall), the spiral gradually increases linearly toward the periphery.

Similarly in the axial direction, 130μm are trimmed off the standard height (40mm). By incorporating these corrections, the problem of contact between the two wraps is effectively eliminated.

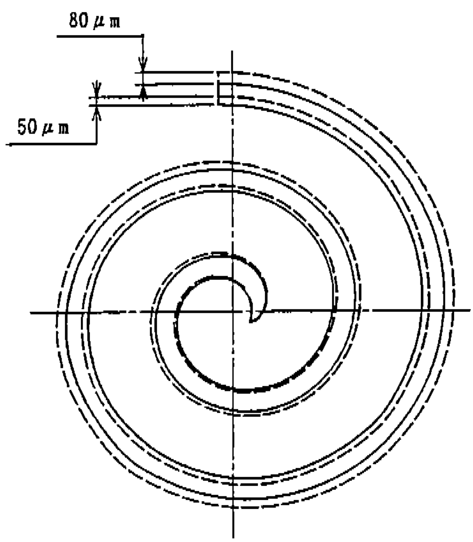


Fig. 5 Modification of the wrap of the orbiting scroll

U.S. patents have already been obtained for these compensation methods.

(2) Constraint by the crank pins

We considered a number of alternatives to overcome the problem outlined above in Section 4.1(2), but eventually settled on the solution illustrated in Fig. 6.

We baked a 3-mm-thick coat of fluororubber around the outside of the needle bearing, which served to elastically absorb all the vibration produced. We arrived at the exact shape and hardness of the rubber coating through a process of trial and error.

This measure proved to be quite effective for reducing the vibration.

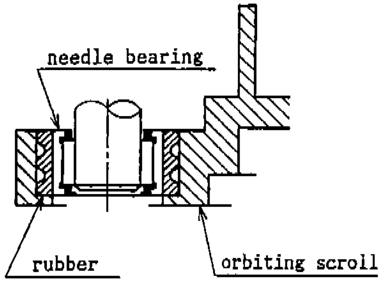


Fig. 6 Needle bearing with rubber baked on

(3) Attainment of target performance

Figure 7 compares the ultimate pressure achievable from a cold start and from a hot start. It can be seen that specified pressure was reached very quickly from the hot start. The importance of maintaining an optimum gap between wraps for pump performance is clearly indicated.

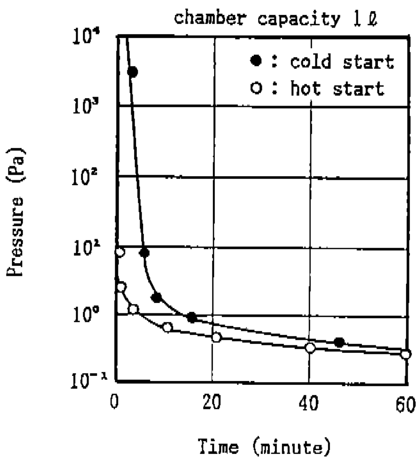


Fig. 7 Ultimate pressure

5.2 Effect of centrifugal force on the orbiting scroll

(1) Motion stabilization

To reduce the moment - the root cause of the instability phenomenon - to zero, the shape of the orbiting scroll has been modified, and stainless steel has been substituted for aluminum alloy for the thrust bearing material. These measures have effectively lowered the center of gravity of the orbiting scroll *G* to that of the roller bearing *B*. As a result, the vibrational acceleration has been markedly reduced by about one-third and the knocking noise has been completely eliminated.

As a result of implementing the countermeasures discussed in Section 5.1 (1), (2), and 5.2(1), the overall vibrational velocity of the pump has been reduces from 4G shown in Fig. 8 to 0.6G shown in Fig. 9.

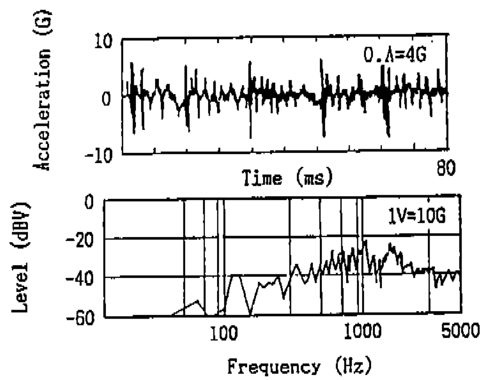


Fig. 8 Vibration
(Before countermeasures)

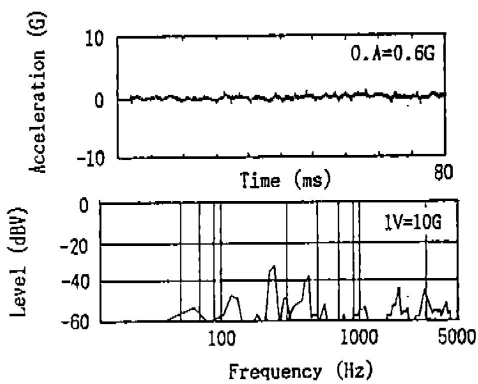


Fig. 9 Vibration
(After countermeasures)

6. CONCLUSIONS

The main conclusions are briefly summarized as follows:

(1) Adopting a scroll structure, a quiet (55dB(A)), light-weight (735N (75*kgf*)) oil-free vacuum pump has been developed.

(2) Beyond the specific issues treated here, we also succeeded in solving a variety of other problems stemming from the elimination of oil. For example, such problems as how to achieve a proper kinetic balance, how to select optimum running clearance, materials, structure, heat processing to ensure the longevity of the bearings, and how to ensure corrosion resistance to process gas and prevent deposition of process gas.